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SMITHSONIAN ASTROPHYSICAL OBSERVATORY

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The Velocity of Faint Meteors

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Abstract.-- Preliminary measurements of meteor velocity to a limiting magnitude of +10 have been obtained with a multi-station radar system. A systematic change in the average velocity of meteors has been found which depends upon the magnitude and hence the size. Between magnitude +6 and +9 the velocity decreases by 5 km sec^{-1}. There are indications that the effect becomes more marked for meteors fainter than +9. This effect is attributed to the difference in orbits within the various meteor populations.

Introduction

The meteor population is size-dependent. McKinley (1961) has summarized the photographic and the radar data, showing that there is a tendency to find short-period orbits amongst the smaller and fainter meteors. This necessarily implies that the average velocity of a group of meteors depends upon the average magnitude, and that small meteoroids tend to move more slowly in space. However, the comparison of the various orbital distributions is fraught with the effects of observational selection, and it is difficult to establish a quantitative measure for the difference between the various meteor populations.

This paper describes a controlled experiment in which the velocity distribution of meteors was measured at several different limiting magnitudes, with the minimization of the various selection effects.

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Observational Data

The multi-station radar system, described by Hawkins (1963), is situated at Havana, Illinois. A single-trough antenna was used at the transmitting site, and single Yagi antennas were used at the five remote receiving sites. The transmitter frequency was 40.92 mcs, and the peak power was varied from 25 kwatts to 2 megwatts. An integration of the ionization curve yields the total number of electrons in the trail, and from this the mass and magnitude of the meteoroid can be computed by means of the values of ionizing efficiency of Lazarus and Hawkins (1963). At low power (25 kw) the average magnitude was +6.6 on the visual scale, and at high power (2 mw) the average magnitude was +9.0.

It was not practical to operate the radar system on a continuous basis, because the number of meteor echoes recorded would have been astronomical. Therefore, an operational schedule was set up based on the days of the week as shown in Table 1. This schedule was used on alternate weeks, with no observations being made on the other weeks. The observing time was cut further by limiting it to the first 30 minutes of any hour during a run. It will be noticed that this schedule gives a uniform diurnal coverage when averaged over a period of one week.

At times it was not possible to adhere strictly to the operating schedule, and observations are not available for the full cycle of 12 months. Thus diurnal and seasonal effects must be taken into account when considering the data. The analysis covers all data available at the present time. The observing periods and power levels are given in Table 2. In the summer and fall of 1961 the radar system was not fully developed and observations were made at only three stations. It will be shown that there is no systematic difference dependent upon the number of stations used. A total of 681 meteors were recorded by the three-station network, but only those periods were chosen for analysis which were reasonably free from shower activity. The number of meteors used was therefore 489. A total of 2398 meteors was available in the initial analysis, of the six-station data, but from this number 216 Geminids and 17 Quadranids were excluded from the final analysis. The velocity was derived from measurements at all stations, using a program on a IBM-7090 digital machine (Southworth, R. B., unpublished). The velocity, v_∞ , has been corrected for atmospheric deceleration.

The Dirunal Effect

The period 15 January to 30 March, 1962 was chosen for a study of the diurnal variation of velocity, because this period contained the minimum departure from the operating schedule (see Table 1). This period was also reasonably free from meteor streams. The data were grouped in six-hour intervals as shown in Table 3, and the velocity distribution was determined for each interval. It can be seen that there are differences in the velocity distribution during a 24-hour period. This is due, of course, to the astronomical selection effect as the earth rotates, and is of no interest in this paper. Rather, the velocity distributions can be used to correct the observations during any period where a complete 24-hour coverage was not available. The correction factors for the period 03-09 hours and 09-15 hours C.S.T. are given in Table 3. It was not possible to determine correction factors for the period 15-03 hours because of the zeros occurring in the velocity distributions.

Results

For the analysis of the velocity distributions, the results have been divided into the 3 groups shown in Table 2. These groups may be classified as low-, medium-, and high-power runs with nominal peak transmitter powers of 25 kwatts, 1 megwatt, and 2 megwatts. The observed velocity distribution was corrected for diurnal effects by use of the correction factor in Table 3 for the periods where the operating schedule was not strictly followed. The corrected velocity distributions for the high- and low-power runs are shown in Fig. 1. The corrected velocity distributions for the medium-power runs are shown in Fig. 2. In Fig. 2 the results have been divided into two groups, the three-station measurements and the six-station measurements. All the velocity distributions have been normalized so that the area under the histogram is equal to 100 units.

The two histograms at a peak power of 1 megwatt were drawn to ascertain whether there were any systematic differences between the three-station and the six-station observations. From Fig. 2 it can be seen that the histograms are essentially the same and that no systematic effects exist. Furthermore, since the three-station results were obtained in the summer months, and the six-station results in the winter months, the similarity of the histograms indicates that there are no significant seasonal variations.

As an internal check, it is possible to verify the diurnal correction factor. One would expect that proper application of the correction factor would yield the same mean velocity for any period of the day at a fixed power level. In Table 4 the observed mean velocity and the corrected mean velocity are shown for the low-power and medium-power observations respectivly. It can be seen that although the observed velocity differs by 1 or 2 km sec^{-1} for the different portions of a 24-hour period used in our investigation, the corrected mean velocity differs by less than 0.5 km sec^{-1}.

The mean velocity for the meteors measured at low, medium and high transmitter powers is given in Table 2. The velocity is plotted as function of transmitter power in Fig. 3, and on the same diagram the average magnitude of meteors in each sample is estimated. Provisional visual magnitudes have been assigned, based on the relation

$$M = 40 - 2.5 \log q, \qquad (1)$$

where q is the electron line density in units of electrons per meter. Thus the curve in Fig. 3 shows a decrease of mean velocity with meteor magnitude. The average decrease is approximately 5 km sec^{-1} for 3 magnitudes. This corresponds approximately to a decrease of 9 km sec^{-1} if one extrapolates to an interval of 5 magnitudes.

Discussion

It is unlikely that these results are affected to any great extent by observational selection. The diurnal effect has been removed, and there are no detectable seasonal effects. It is possible for a bias to be introduced that is dependent upon the mean height of meteors in the various samples. For example, if the faint meteors were occurring at a greater height, then it is possible for these meteors to be inadequately observed because of the effects of diffusion of the trail (McKinley, 1963). An analysis of the heights of the echoing points has been made in connection with a study of the physical characteristics or radar meteors (Hawkins and Southworth, 1963). This work shows that the faint meteors occurred at a lower height in the atmosphere than did the bright meteors For example, in the velocity range 25-30 km sec^{-1} the mean height was 94.5 km for meteors with magnitudes between +5.7 and +6.9. On the other hand, meteors with magnitudes between +9.0 and +9.9 occurred at a mean height of 88.4 km. This result is in complete disagreement with the single-body classical theory. The discrepancy is probably due to the change in physical characteristics that is found as one proceeds to fainter meteors. Whatever the cause, the height distribution is certainly not responsible for the observed difference in mean velocity.

It can also be shown that the low velocity of faint meteors is not due to a preliminary deceleration in the exosphere or Van Allen belts before ionization is detected. The mean geocentric velocity (V_G) of 216 Geminid meteors recorded at a power level of 1 megwatt was 34.5 km sec^{-1} and the corresponding photographic value for 50 Super Schmidt and small camera meteors was 34.0 km sec^{-1}. These values are in substantial agreement and indicate no difference in the velocity of the Geminid stream between magnitude 0 and +8.

It is interesting to compare the data obtained by the radio meteor project with data from other observatories. The only available data are those of Davies and Gill (1960), who carried out a meteor survey at Jodrell Bank, England. The average magnitude of meteors in their sample was +7 and the radar wavelength was 8 meters, which is close to the 7-meter wavelength used in the radio meteor project. From the published data of Davies and Gill, two values for mean velocity have been determined. The results are plotted in Fig. 3. The first value represents the original observational data. The second value is a corrected value, which allows for the difficulties of observing the Fresnel pattern. No correction for visibility of the pattern has been included in the data in this paper. However, the Fresnel patterns as recorded are somewhat clearer than the Jodrell Bank records, and we consider that our data corresponds to an intermediate value between the corrected and uncorrected data of Jodrell Bank. On the basis of this comparison the agreement with the Harvard radio meteor data is satisfactory.

Between a visual magnitude of +6 and +9 the average velocity of meteors decreases by approximately 5 km sec^{-1}. Thus, in interplanetary space the average velocity of meteoroids will depend to a considerable extent upon the mass of the particle. There are indications that the change in the meteoroid population becomes accentuated among the smaller particles. The curve in Fig. 3 becomes much steeper between magnitude +8.5 and +9. The meteor population may undergo critical changes between magnitude +9 and +12, and it is hoped to investigate this region of the magnitude scale with a further extension of the sensitivity of the radio meteor project.

References

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TABLE 1

Operating Schedule

Day	Hours
Monday	0000 to 0800 C.S.T.
Tuesday	0000 to 1200 C.S.T.
Wednesday	0800 to 1600 C.S.T.
Thursday	1200 to 2400 C.S.T.
Friday	1600 to 2400 C.S.T.

TABLE 2

Velocity at Various Power Levels

Observational Periods		No. of stations	Power (kw)	Observed velocity	Corrected velocity	No. of meteors	Hours of obs. C.S.T.
15 April-31 Aug	1961	3	25	39.8	38.4	378	03-15
27 - 28 Nov	1961	6	25	38.2	35.9	39	03-09
Mean			25		38.1		
4 December	1961	6	700	39.9	37.5	49	03-09
15 Jan-2 Feb	1962	6	750		34.9	409	00-24
2 - 5 Jan	1962	6	900	35.5	34.7	93	09-15
19 June-8 Aug	1961	3	1000	37.1	36.1	111	03-15
5 - 15 Dec	1961	6	1200	40.6	38.1	451	03-09
Mean			950		36.4		
26 Feb-16 March	1962	6	1750		33.3	463	00-24
26 - 30 March	1962	6	1750		31.4	212	00-24
12 - 16 Feb	1962	6	2000		34.3	276	00-24
9 - 27 April	1962	6	2500		30.9	173	00-24
Mean			1900		32.8		

TABLE 3

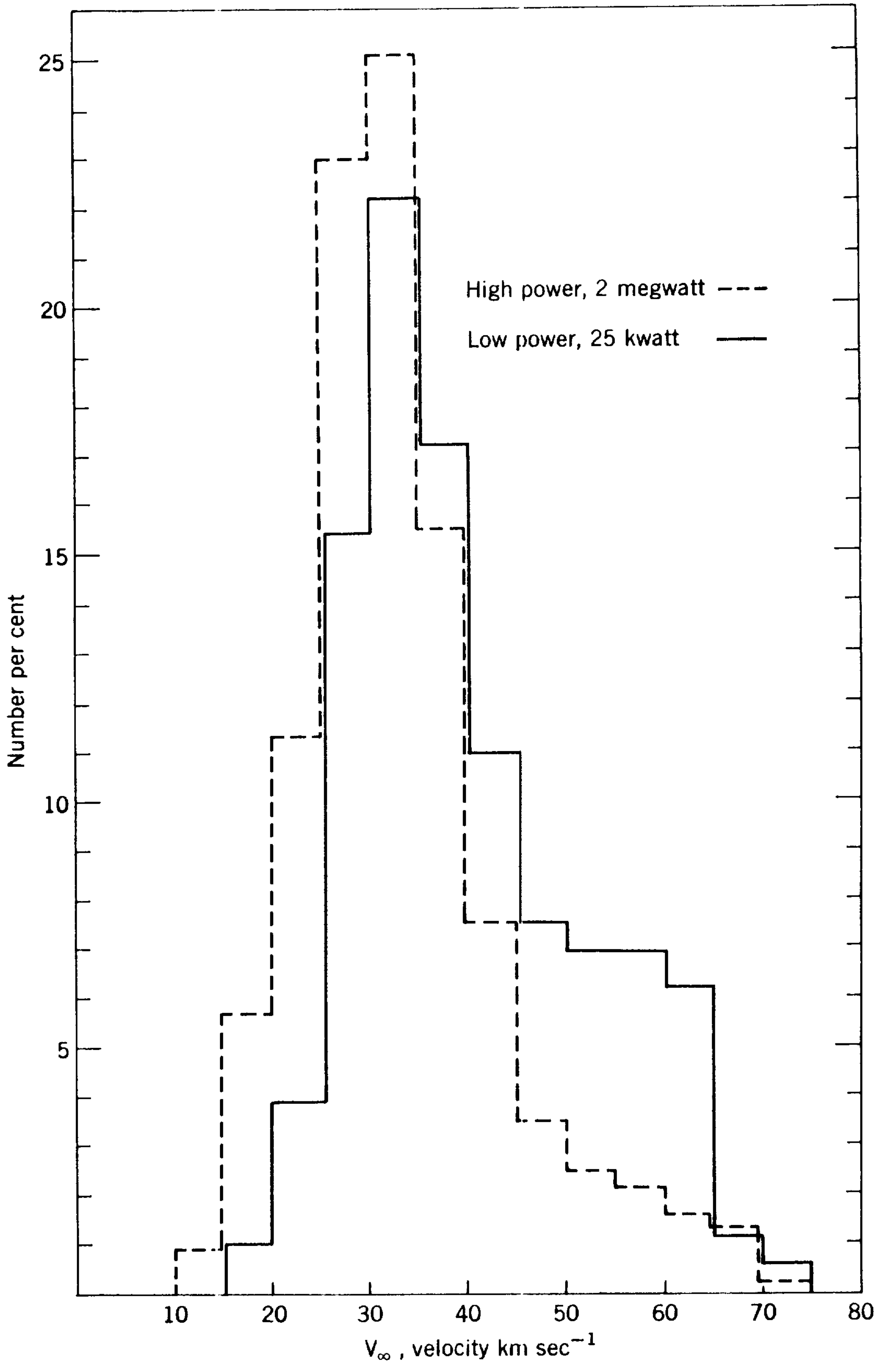
Diurnal Velocity Distribution

V_∞	Velocity distributions for period 15 Jan-30 March 1962				Correction factor to reduce to 24 hrs of observation	
V km sec^{-1}	03-09	09-15	15-21	21-03	03-09	09-15
10.0-14.9	2	0	7	1	5.00	-
15.0-19.9	16	15	20	15	4.13	4.40
20.0-24.9	53	56	37	23	3.00	3.11
25.0-29.9	127	129	26	24	2.41	2.41
30.0-34.9	143	142	16	8	2.12	2.21
35.0-39.9	93	109	1	7	2.19	1.97
40.0-44.9	42	59		3	2.48	1.76
45.0-49.9	20	27		1	2.40	2.40
50.0-54.9	15	17			2.13	1.88
55.0-59.0	26	12			1.46	3.17
60.0-64.9	22	6			1.27	4.67
65.0-69.9	16	5			1.31	4.20
70.0-74.9	3	1			1.33	4.00
Total	593	578	107	82		

TABLE 4

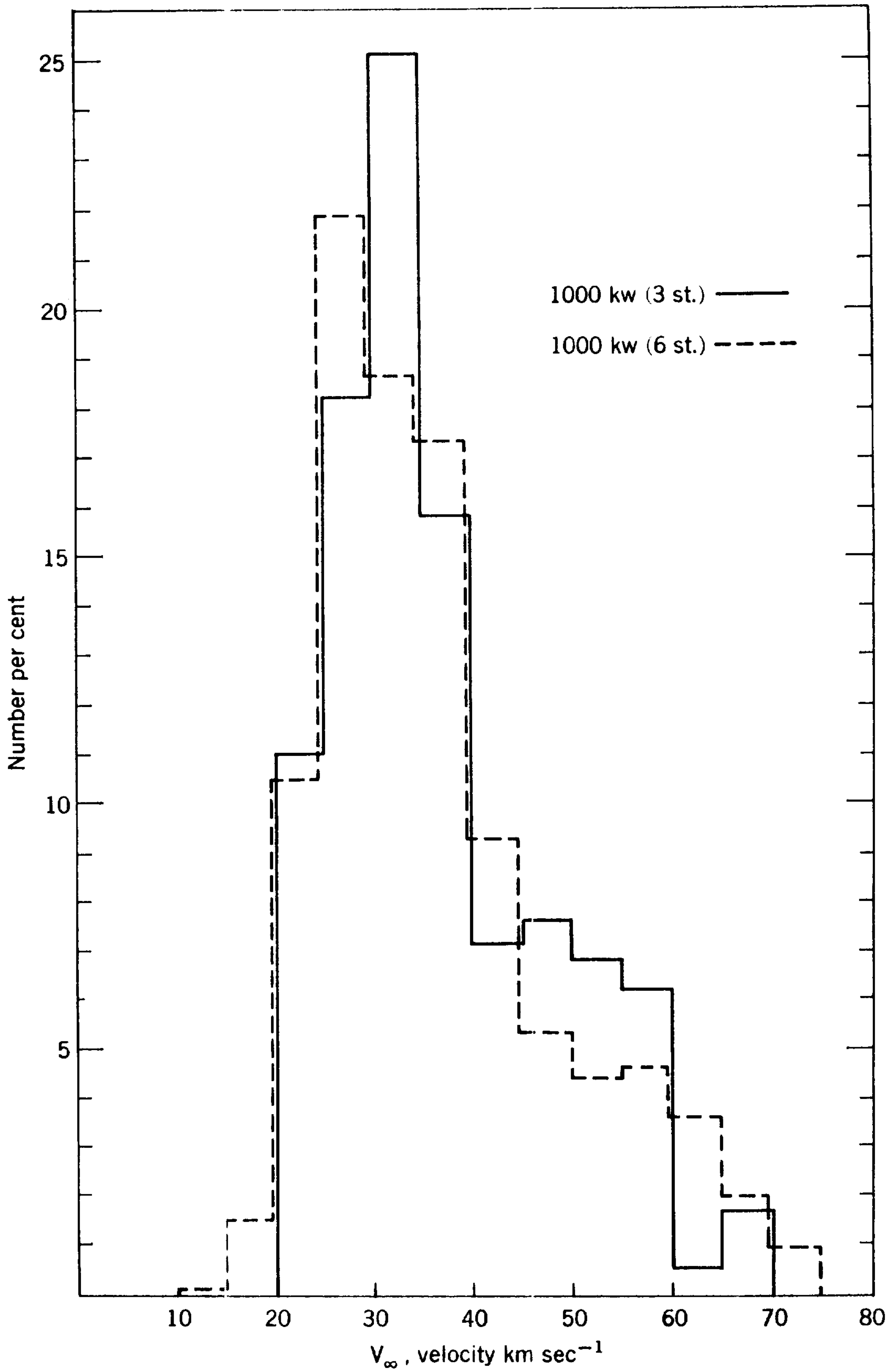
Verification of Diurnal Correction Factors

Observational Periods	Power (kwatt)	Observed mean velocity km sec^{-1}	Corrected mean velocity km sec^{-1}	No. of meteors	Hours of observation
15 April-31 Aug	25	41.1	38.6	143	03-09
1961	25	39.0	38.2	236	09-15
19 June-8 Aug	1000	38.7	36.4	20	03-09
1961	1000	36.8	36.0	91	09-15



High power, 2 megwatt
Low power, 25 kwatt
Number per cent
25
20
15
10
5
10
20
30
40
50
60
70
80
V_∞, velocity km sec^{-1}

FIGURE 1



25
20
15
10
5
Number per cent
1000 kw (3 st.)
1000 kw (6 st.)
10
20
30
40
50
60
70
80
V_∞, velocity km sec^{-1}

FIGURE 2

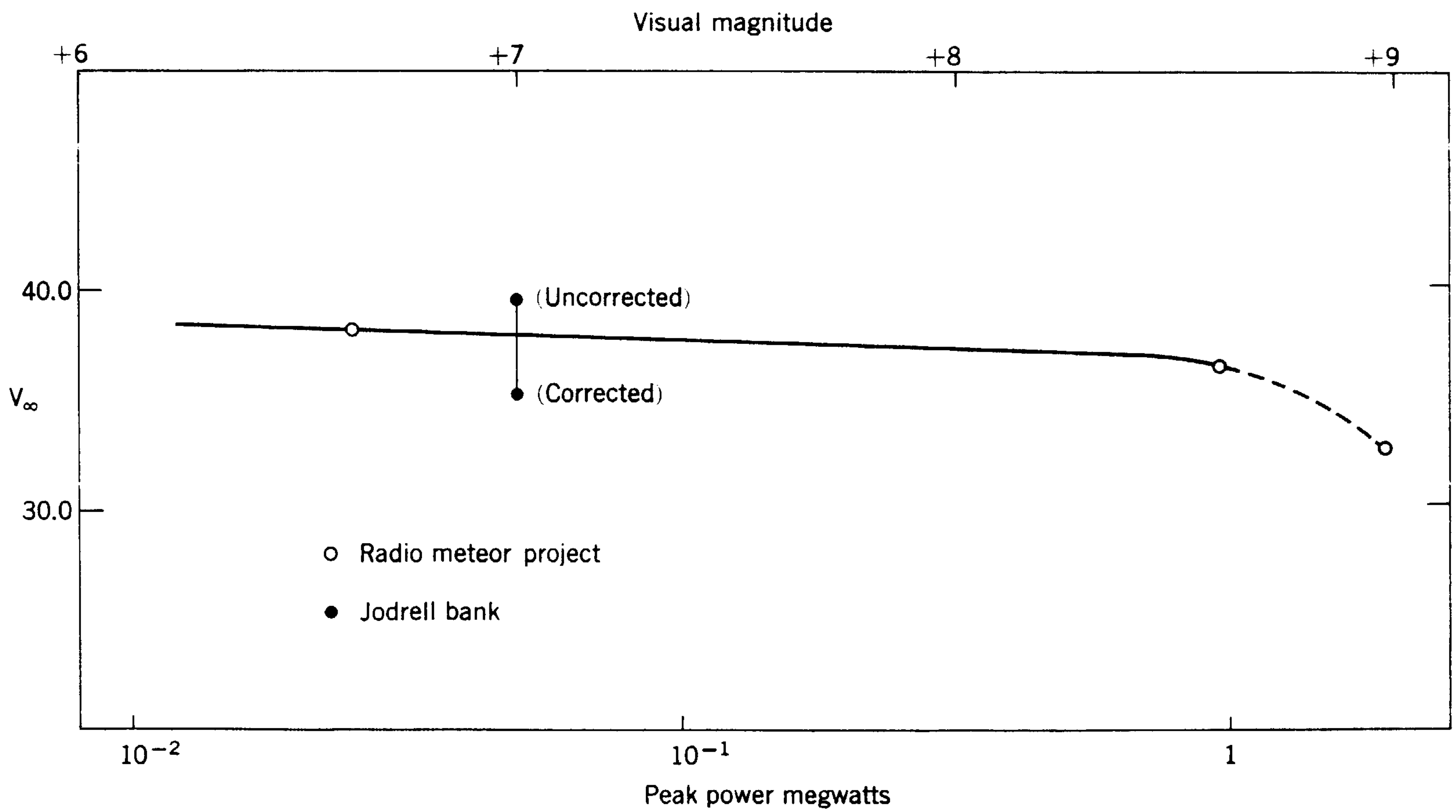

Visual magnitude
+6
+7
+8
+9
40.0
30.0
V∞
(Uncorrected)
(Corrected)
Radio meteor project
Jodrell bank
10−2
10−1
1
Peak power megwatts

FIGURE 3